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Pulse Echo Measurements on Telephone and Television Facilities

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Synopsis: Pulse echo measurements have been used on telephone and television facilities since 1940 to locate impedance irregularities and control quality in manufacture and installation. These sets send a pulse into a line and observe on an oscilloscope the echoes returned from irregularities. The shape and width of the pulse, the rate at which it is repeated and the pulse magnitude are important in determining the accuracy of the results and the requirements of the measuring apparatus. The "coaxial pulse echo set" is used for factory and field testing of coaxial cables. The "Lookator" was developed for use on much narrower band systems such as spiral-four field cable and open wire lines.

THIS paper describes means of making pulse echo measurements on telephone and television facilities to locate irregularities and to control quality in manufacture and installation. The first practical use of this sort of measurement started in 1940¹ to control the manufacture of coaxial cable facilities by means of the "coaxial pulse echo set." This set has been improved and its use extended to include field testing of coaxial cables during and after installation to insure proper installation methods, to set deviation limits, to locate irregularities, and so forth. The second practical device is the "Lookator," built for the Signal Corps during the war to test spiral-four field cable, open-wire lines; and other facilities and to locate gross

troubles and irregularities in such lines. The two devices have quite different frequency ranges and equipment requirements, but are basically similar in their general principles of operation.

The first part of this paper discusses general principles and limitations of such sets, the second part discusses the coaxial pulse echo set and the third part discusses the Lookator.

General

Figure 1 shows the general operating features of both types of pulse echo set. The base oscillator controls the device which originates the pulses, sending such pulses into the test line once every base oscillator cycle. It also controls the sweep generator, which in turn controls the horizontal progress of the trace on the cathode-ray oscilloscope, with one complete horizontal sweep every base oscillator cycle. The transmitted pulse goes through the hybrid coil and out over the connected line. Irregularities in the line reflect echoes toward the sending end, which are amplified and delivered to the vertical plates of the scope, thereby controlling the vertical motion of the cathode-ray trace. With a regularly repeated sweep and transmitted pulse, the result is a stationary trace on the scope with the horizontal scale showing time or distance along the test line and with the vertical height showing the magnitude of any irregularities causing echoes. The hybrid coil and balancing network reduce the part of the original pulse that enters the receiving circuit directly so that overload-ing due to this pulse does not occur, thus

making electronic cutoff during the transmission of the pulse unnecessary. A terminating network at the far end of the line may be adjusted to terminate the line as well as possible, thus reducing the echo returned from the distant end. Alternatively, the normal working termination may be used, or under some circumstances the distant end echo may be ignored since it is separated in time. The adjustments of the balancing network and terminating network for minimum original pulse and distant end echo also indicate the impedances of the input and distant ends of the line, respectively.

By means of the phase shifter between the base oscillator and the sweep generator, the horizontal position of the pattern may be shifted back and forth as desired. A comparison of the phase shift setting which, say, lines up the part of the original pulse across the hybrid with a reference point and the later setting, which lines up the echo from an irregularity at the same reference point, determines the delay from the sending end to the irregularity and therefore the distance to the irregularity.

The pulses used with these devices are d-c pulses rather than a-c pulses such as are used in radar. Figure 2 illustrates the approximate appearance of a repeated d-c pulse wave versus time. Here d is the pulse width normally measured at half of the maximum amplitude of the pulse and $D = 1/f$, is the pulse spacing or repetition time, with f , being equal to the repetition frequency. These two factors plus the pulse shape and amplitude entirely define the pulse.

The Fourier analysis of such a succession of pulses consists of the repetition frequency and all its harmonics to infinity, plus a d-c component. To preserve the shape of the transmitted pulses or their echoes, the measuring set and the line on which it is used must be relatively free of delay and gain distortion throughout a wide frequency band. If excessive distortion were present, various amounts of the distorted frequencies would seem to appear in the part of the cycle between pulses where the current without echoes should be zero, thus confusing the inter-

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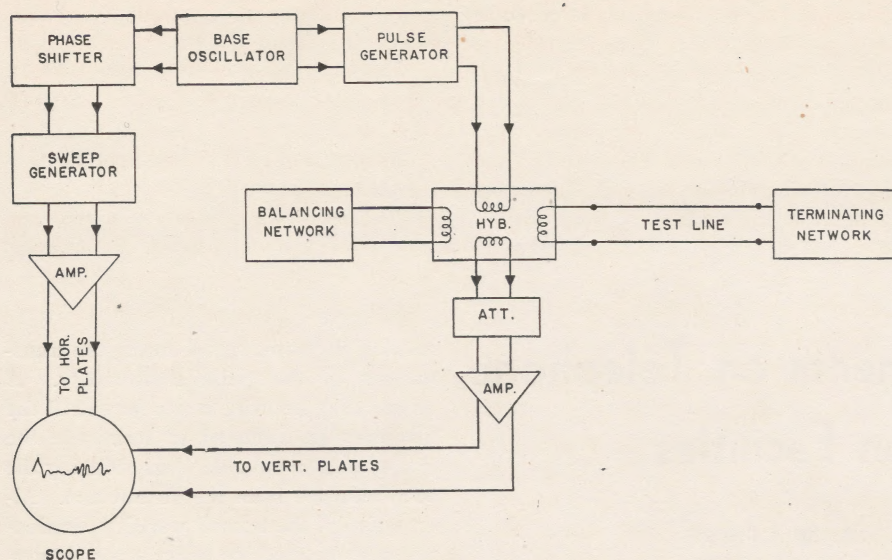


Figure 1. Block diagram of pulse echo sets

pretation when echo currents are received in that interval.

The choice of a repetition frequency depends upon a number of factors. The time between pulses must be long enough or the repetition frequency low enough so that all echoes it is desired to inspect and any longer delay echoes which are large enough to cause interference are returned before a second pulse is sent out. At the same time, the repetition frequency must be high enough so that excessive low frequency delay or gain distortion will not be encountered in the line or measuring set.

The pulse width for a given shape needs to be small in order to accurately locate irregularities, to separate nearby irregularities and to observe the impedance over the desired frequency range for the facility in question. At the same time, the pulse should not be any shorter than is necessary, since for a given pulse shape the effect of line distortion and of measuring set distortion at high frequencies increases as the pulse width decreases.

A resistance irregularity returns a copy of the arriving pulse and the accuracy of location is generally inversely proportional to the pulse width. In addition, when reactance irregularities are encountered, as will be discussed later, the echo of a pulse assumes a shape which is approximately that of the derivative of the original pulse shape with both a maximum and a minimum. Under such circumstances, the maximum and minimum of the pulse echo are each roughly one-quarter pulse width from the true location, for the shapes of pulses considered most desirable.

If two irregularities are close together in a line, a wide pulse will return an inte-

grated total of the irregularities and the two may be very difficult to separate. This is because the return of the two echoes may differ in time by only a fraction of a pulse width so that the lesser echo may be hidden within the greater or, if both echoes are approximately the same size, only a single irregularity may seem to be present. In theory, with two such similar irregularities, the returned echo trace will be wider than with one irregularity and the two might be separated by means of that information. In practice, with different types of irregularities and with many small irregularities present, it is very difficult to separate irregularities which are much less than one pulse width apart.

In order to inspect the entire frequency range of interest on the line being tested, it is desirable to have harmonics present over this entire range. This is particularly true if types of irregularities are present which vary in magnitude over the frequency range. On the other hand, it is desirable to have the magnitude of the harmonics decrease as quickly as possible above the range of interest because

1. Such harmonics return irregularity information which may be misleading.
2. Line distortion generally is greater there than within the important range.
3. The requirements on the delay and gain characteristics of the measuring set extend up to the point at which the relative power in the higher harmonics becomes small enough to be neglected.

The shape of the distribution of such harmonics is determined by the pulse shape. In general, the simplest thing to use is a half sine wave pulse and an approximation of this has generally been

used in devices built to date. However, from theoretical considerations, the raised cosine-wave pulse should be considerably better than a half sine wave pulse and either of these much better than a rectangular pulse. A Gaussian law pulse is probably also good and may be easier to handle analytically. Figure 3 shows four pulses that were considered in some detail in selecting an optimum pulse.

Figure 4 shows the distribution of harmonics of these various pulses plotted against the relative frequency of the harmonics. All harmonics are assumed to be positive in magnitude although alternate groups would have different signs. At a relative frequency of 1.0, the absolute frequency is $1/d$ (see Figure 3) for these pulses and the first zero magnitude occurs at this point. The amplitudes are all expressed in decibels down from the magnitude of the repetition frequency current.

It may be seen that the distribution of the harmonics up to a relative frequency of 1.0 is about the same for all the pulses, thus making them about the same from the standpoint of the criterion that they should cover all parts of the desired frequency range approximately equally. The main differences between the harmonic distributions for the various pulses are at higher frequencies which are important because there the harmonics may be distorted in amplitude or phase by the line or by the measuring equipment. When the power in these harmonics is quite small, it does not matter what is done to them in phase or extra loss or whether or not small amounts of extra gain are inserted. Eliminating the higher harmonics completely would be equivalent to adding similar harmonics of equal magnitude but 180 degrees out of phase. If such an addition is far enough down in magnitude, no effect will be observed on the oscilloscope. No amount of phase shift can be any worse than this.

Just how far these harmonics must be down in a particular case is a complex combination of the hybrid balance at high frequencies, the irregularities in the line at such frequencies, the sensitivity of the measuring set, the rate at which further harmonics decrease, the way in which the remaining currents add, and so forth. As a first approximation, suppose it is assumed that when the harmonics beyond a given frequency are 30 decibels down, the higher frequencies may be ignored as far as loss or phase distortion is concerned.

On this basis, the loss and phase distortion may be neglected for the raised cosine wave above a relative frequency of

about 0.9, for the half sine wave above a relative frequency of 1.5, for the isosceles triangle above a relative frequency of 1.6 and for the rectangular pulse above a relative frequency of about 10. These figures show in a rough way the relative difficulty of building satisfactory measuring equipment for the different pulse shapes. For example, if a receiving amplifier well equalized for gain and phase up to 5 megacycles were needed for a given width of raised cosine pulse, the half sine pulse of the same width would need an 8-megacycle amplifier, an isosceles triangle pulse of that width a 9-megacycle amplifier and a rectangular pulse of that width about a 50-megacycle amplifier.

Similarly, the weighted average line attenuation to a pulse is decreased by shaping the pulse in this way, even before the distortion becomes noticeable on the oscilloscope. Experiment has shown noticeable reduction in the pulse attenuation of a given type of coaxial cable for slightly more optimum pulse shapes. In looking at irregularities at considerable distances, the better shape of pulse is doubly important because the reduced attenuation permits the pulse echo to be larger as received and also because the total noise is less due to the reduced frequency band necessary in the receiving

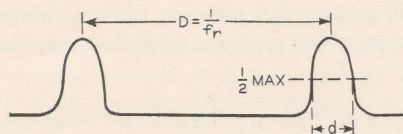


Figure 2. Repeated pulses

circuit. Practically, the pulse attenuation and pulse delay are determined experimentally by measurements on lines. The pulse loss per mile decreases as the length of line increases, particularly for the first part, because the higher frequencies disappear soon and further attenuation acts on lower and lower frequencies where the average attenuation is less.

It is possible to insert equalizers in the sending or receiving circuit to correct for the line distortion to a pulse echo from any particular point. This is of somewhat limited value, in general, however, because nearby echoes then are more distorted. A compromise value is often worth while.

The pulse magnitude to be used is partly a question of the needed signal-to-noise ratio for echoes versus the line and set noise, partly a question of what voltage is permissible on the lines, and partly a matter of the magnitude which it is

practicable to get from available tubes with available power supplies, and so forth. Within these limits, the higher the pulse magnitude is made, the better, because higher magnitudes permit overriding noise and using minimum gain in the receiving circuit, but this should not be done at the expense of distorting the pulse.

Description of Coaxial Pulse Echo Test Set

The present coaxial pulse echo test set represents continued development of the original circuit which was first used in 1940 for factory testing of coaxial cables. There have been changes in the direction of increasing the sensitivity and accuracy of measurement and the ease of measurement.

On a smooth line, the present measuring equipment can detect an isolated irregularity which gives a reflection approximately 100 decibels below the test pulse. The location of an irregularity is dependent upon a number of factors such as pulse width and the nature of the irregularity. With the 0.25-microsecond pulse in the present field test equipment, the position of an isolated irregularity not too distant from the sending end may be measured to about plus or minus 50 feet. Complex echoes make recognition and isolation of irregularities considerably more difficult and in the usual length of manufactured cable, echoes approximately 75 decibels down from the transmitted pulse are about the determinable minimum.

Figure 1, which is a general schematic diagram of the pulse echo sets, is representative of a coaxial pulse echo set. In the coaxial set, however, a compensating network to be discussed later is shunted across the coaxial cable at the sending end. The following is a detailed description of a Bell Laboratories model used to measure coaxial cables in the field.

Figure 5 is a schematic diagram of the pulse and sweep generators. The wave shapes indicated near the several components serve to represent the approximate shapes of the waves with no attempt being made to indicate their relative magnitudes or durations. The oscillator which is a sine wave resistance capaci-

tance oscillator is arranged to furnish either 56, 13, or 3.3 kc. The rates at which pulses are generated and at which the horizontal sweep is repeated are both controlled by the particular oscillator frequency and are thereby kept in synchronism.

To generate the pulses required, the sine wave is first squared in an over-loaded amplifier, clipped, and used to trigger a start-stop multivibrator circuit. The output of the multivibrator is connected to a circuit tuned to produce the desired pulse width of 0.25 or 1.5 microseconds (a 0.08-microsecond pulse is now under development). A damping diode is also connected across the tuned circuit. The normal response of the tuned circuit to the square pulse output of the multivibrator would be a train of oscillations. However, the diode acts to absorb the energy in the tuned circuit after the first half cycle in the negative direction, which occurs at the front edge of the multivibrator pulse, and to greatly reduce the output by absorbing the energy in the trailing edge of the multivibrator pulse. The resulting pulse at the output of the tuned circuit is approximately a half sine wave and is fed into a pulse amplifier which includes an output stage biased beyond cutoff. This serves to remove most of the residual undershoot due to the imperfect damping action of the diode.

The output of the pulse amplifier is connected to the hybrid coil circuit by means of an output transformer. The high impedance side of the transformer is terminated in a resistance so that its output looks like approximately 75 ohms. The transformer is designed to deliver 35- to 40-volt positive pulses to a 75 ohm load.

The portion of the base oscillator output which is used to derive the horizontal sweep of the oscilloscope is first fed through a phase splitting and inverting circuit and a variable phase shifting circuit. The latter is a standard 4-stator variable capacitor where quadrature voltages are applied to the four plates and a single rotor used as a pickup device. The varying positions of the rotor give a change in phase over the full 360 degrees. The output of the phase shifter is ampli-

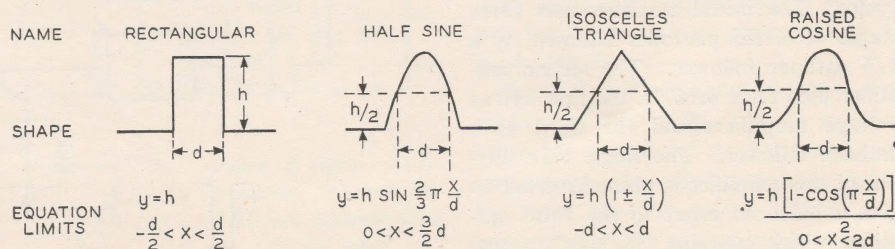


Figure 3. Pulse shapes

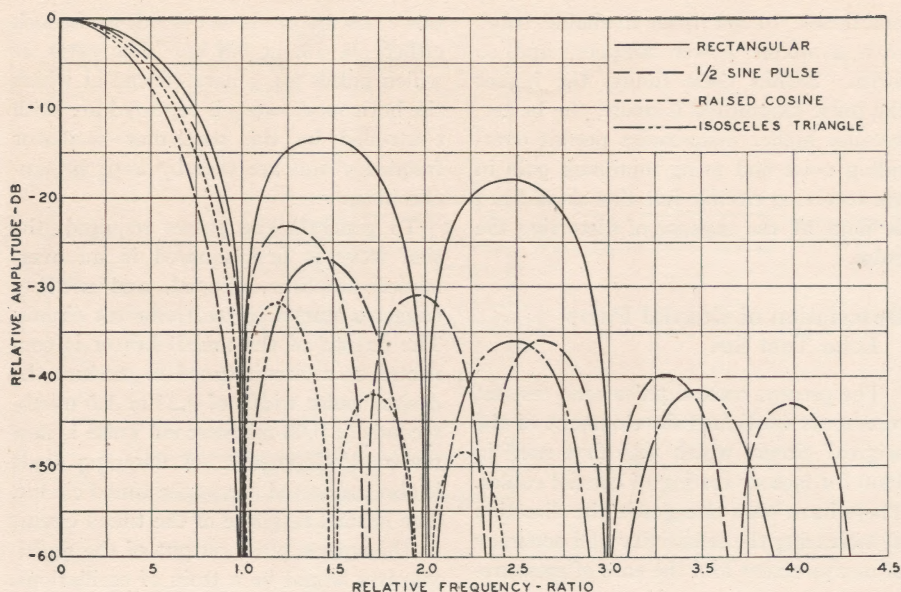


Figure 4. Distribution of harmonic frequencies of various shapes of repeated pulses

fied, squared, and differentiated to give positive and negative short pulses which are applied to a clipper tube. The positive pulse is flattened while the negative pulse is amplified and used to trigger the multivibrator which in turn drives a sweep generator tube. The length of the sweep is determined by the length of the multivibrator pulse. The sweep generator is a switching tube which is normally conducting and which is driven beyond cut-off by the output of the multivibrator. A capacitor in its plate circuit charges exponentially toward the positive plate supply voltage when the tube is cut off and by using only a small portion of the exponential rise a reasonably linear sweep is secured.

The vertical deflection system for the cathode-ray oscilloscope employs essentially a 12-tube amplifier which is composed of three individual amplifiers for practical reasons. The amplifier combination has a reasonably constant time delay up to 5 megacycles and a gain characteristic which is flat to within plus or minus 2 decibels between 2.5 kc and 5 megacycles. Above and below this frequency band, the gain of the amplifier decreases gradually, the 10-decibel points being at approximately 1 kc and 10 megacycles. The initial amplifier uses three stages of 6AK5 pentodes followed by a 6J6 cathode follower. The second amplifier uses three 6AC7's, the first two as voltage amplifiers and the third as a cathode follower. The single tube output of this amplifier is phase inverted to give a balanced input to the third amplifier which contains two 6AC7's, two

6AG7's and an 829 tube to provide three balanced stages of amplification. The vertical deflection plates of the 5-inch cathode-ray tube are connected to the plates of the 829 output stage.

The 4-winding hybrid coil (Figure 1) is used to transmit the pulses to the cable under test and to balance them out of the vertical deflecting circuit. A variable attenuator at the input of the vertical deflecting circuit serves as a gain adjustment and calibrating device. Since, in general, the cable under test is not directly accessible to the terminals of the test set, a 50-foot length of flexible coaxial cable is included for connection to the test sample. To simplify the balancing problem, an identical electrical length of

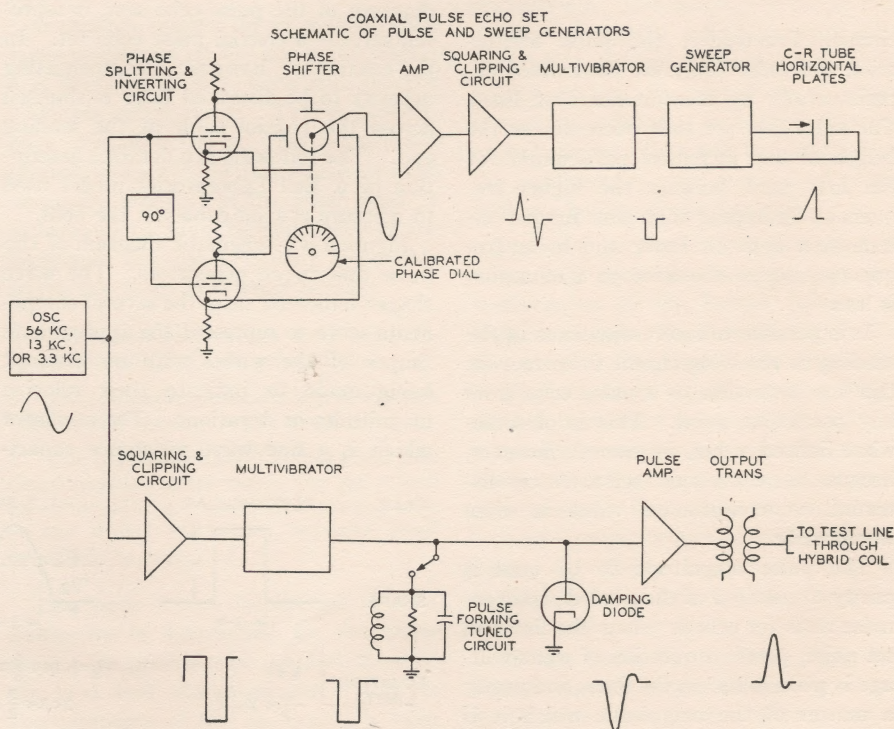
flexible cable is used to connect the balancing network to the conjugate winding of the hybrid coil.

In order to secure the desired balance of approximately 80 decibels, the balancing network would be necessarily complex since it must match the cable resistance and reactance to a high degree of accuracy over a wide frequency range. However, the use of a compensating network, as discussed later, serves to make the combination of the cable and network look like a pure resistance. The balancing network, therefore, can be a simple resistance network as shown in Figure 6. A small variable capacitor is included to correct any small deviations in cable reactance, and so forth.

The cable under test also must be terminated accurately if large terminal reflections are to be eliminated. A complex terminating network which matches the cable impedance closely over a wide range of frequencies is necessary in this case. Figure 7 illustrates a typical network.

As indicated in the general discussion, the application of a pulse to a resistance does not change the general shape of the pulse. The impedance of a coaxial cable, however, is not a pure resistance since it contains both resistance and reactance components. When a pulse is applied to coaxial cable, pulse distortion will occur. For example, when a voltage source which produces a small rectangular

Figure 5. Coaxial pulse echo set sweep generator and pulser

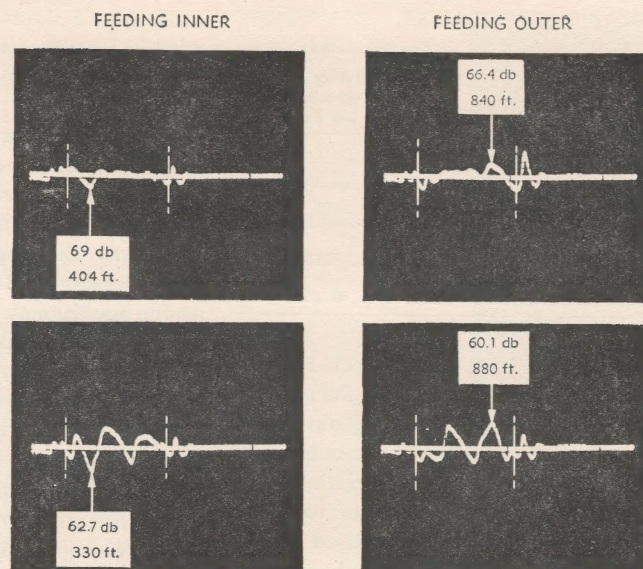


pulse of voltage is connected in series with a coaxial cable terminated in characteristic impedance, computations indicate that the resulting current produces a voltage across the near end of the coaxial cable which does not restore to zero immediately at the end of the pulse. It does fall to a small value and then decreases very gradually. A network (shown in Figure 8) called a compensating network is therefore connected in parallel with the cable under test. This combination looks effectively like a pure resistance over the frequency band involved. The use of this network for all practical purposes eliminates the pulse distortion from this source and, as indicated previously, permits the use of a very simple balancing network.

For quality control of manufactured cables, it is desirable to note the magnitude of the echoes as well as their position in the reel. The magnitude of echoes is measured by initially opening or shorting the line side of the hybrid coil. This permits the pulse normally applied to the cable to be transmitted to the vertical deflection system. With an 80-decibel loss in the input variable attenuator, the variable gain control in the vertical amplifier is adjusted for a reference deflection. The hybrid coil is then reconnected to the coaxial under test and the magnitude of any echo may be determined by adjusting the variable attenuator for reference deflection. The difference in attenuator readings is then directly the ratio of the reflected pulse to the applied pulse.

Measurements of distance to an irregularity are made with the phase shifter in the sweep circuit. Several methods of doing this are possible. For the set now being used in the field, the phase dial is divided into uniform divisions. Calibration curves for the several pulse widths and sweep lengths showing the

Figure 9. Coaxial echo traces



experimental relationship between phase dial divisions and known lengths of cable have been prepared. A small mismatch is inserted at the input of the section under test by degrading the balance across the hybrid with the balancing network. The reading of the phase dial to bring the initial echo to a reference line on the scale is then noted. The phase dial reading required to bring any particular irregularity to the same reference line is also noted. Distance along the cable to any irregularity may then be determined by converting the two phase-dial readings to feet and taking the difference between them.

Another method, where the length of the cable under test is known, is to degrade the balance across the hybrid coil with the balancing network to give a well defined echo at the sending end, and to adjust the phase dial so that this echo coincides with a vertical line on the oscilloscope scale. The terminating network may then be adjusted to give a sizable echo at the end of the cable section. The phase dial is

readjusted to bring the terminal echo to the reference line on the scale and the reading noted. The difference between the two phase-dial readings is the length of the cable in phase-dial divisions. With the networks restored to their normal operating condition, the phase-dial reading required to bring any particular irregularity to the reference vertical line is noted. The difference between this phase-dial reading and the phase-dial reading locating the near end of the cable is the distance to the irregularity in phase-dial divisions. The distance to the irregularity in feet is then determined by proportion. This method is less accurate than the preceding one because it assumes a linear relationship between length of cable in feet and the phase-dial readings.

In manufacture, the usual reel length of coaxial cable is approximately 500 to 1,500 feet and the set has been used extensively with this length of sample. It may also be used as a field test set where the lengths of cable in question may be up to that between repeaters, or about eight miles. The sensitivity for echoes returned from considerable distance is, of course, considerably less due to the attenuation of the pulses in the cable.

The round trip pulse attenuation per unit length varies with the total length from the sending end to the irregularity. Table I shows typical values determined for nominal 0.25- and 1.5-microsecond pulse widths on various lengths of 0.27- and 0.375-inch polyethylene disk insulated coaxials.

Figure 9 shows irregularities on a reasonably smooth cable and on a cable which has several fair sized irregularities. The pictures were taken from each end of the two 1,265-foot cables. Those pictures designated "feeding inner" indicate

Figure 6 (right). Balancing network

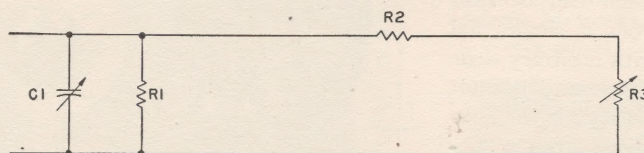


Figure 7 (right). Terminating network for 0.27-inch polyethylene coaxial cable

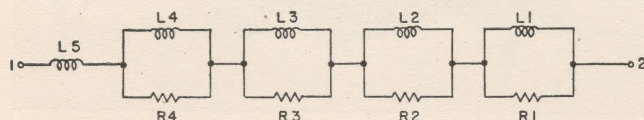
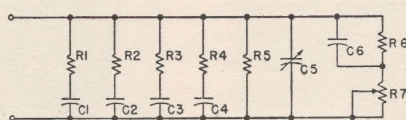


Figure 8 (left). Compensating network for 0.27-inch polyethylene coaxial cable

Table I

Distance to Irregularity, Feet	Round-Trip Attenuation—Decibels Per 100 Feet		
	1,000..	2,000..	20,000
0.27-inch coaxial, 0.25 microsecond.....	0.22..	0.21..	0.15
0.375-inch coaxial, 0.25 microsecond.....	0.15..	0.15..	0.11
0.375-inch coaxial, 1.5 microseconds.....	0.10..	0.10..	0.07

that the echo set was connected to the inner end of each coaxial on the reel and for those designated "feeding outer" the echo set was connected to the outer ends. The 0.25-microsecond pulse width and the 56-kc repetition rate were used to obtain these pictures. The designated echoes are the same echoes measured from opposite ends of the reel. The figures in decibel indicate the magnitude of the echo at the point at which it exists. The locations in feet are the distances from the measuring end of the circuit. It is interesting to note that the peak of the echo in each case turns over, that is, is of opposite sign, when measured from opposite ends of the reel. This would indicate that these were impedance irregularities, that is, a change in characteristic impedance so that the pulse went from low to high impedance when sent from one end and from high to low impedance when sent from the other end.

Lookator

An example of the practical application of the echo time measuring technique as a fault finding means on voice frequency telephone circuits is found in the Lookator.² When connected to a telephone circuit of favorable characteristics, the Lookator shows departures from the normal impedance of the circuit along its length by means of a trace on a cathode ray tube. If steady or swinging faults of a magnitude sufficient to cause appreciable impedance irregularities are present, their general nature can be at once detected and their distance from the Lookator measured. The device is thus a fault locator that permits the operator in effect to "look" out over the circuit and it seemed appropriate to call the instrument a Lookator.

Figure 10 shows a front view of the Lookator with cover removed and ready for use. A 110-volt a-c power source capable of supplying 150 watts is required for operation. The instrument is shown housed in a carrying case approximately 19 by 19 by 15 inches and weighs approximately 100 pounds complete with case.

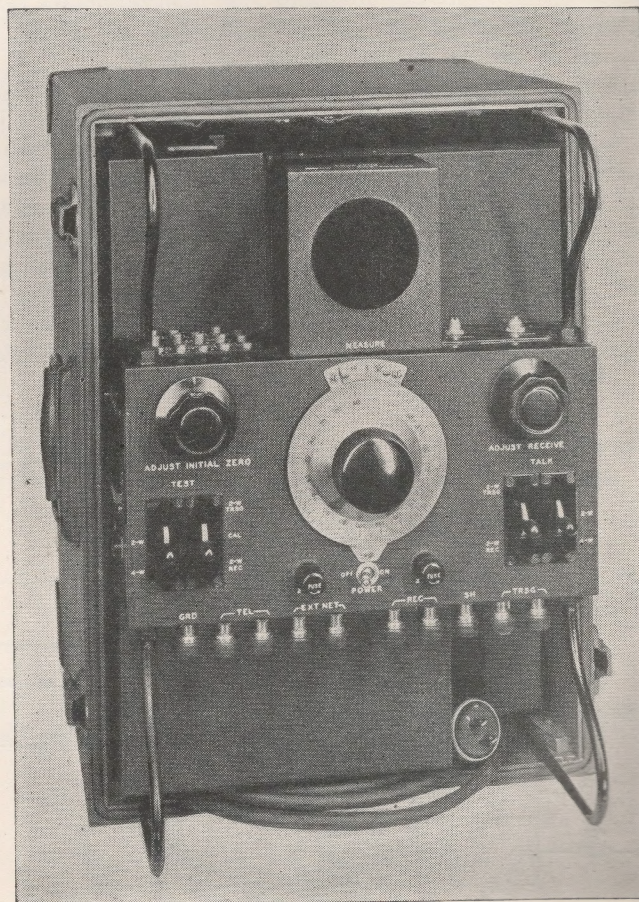
Figure 11 shows the functional setup used in locating faults by connecting the Lookator directly to a 2-conductor telephone circuit. The bridge-stabilized 220-cycle oscillator feeds through a zero adjustment circuit into a pulse generator where the oscillator frequency controls the repetition rate. The pulses, having individually the approximate shape of a positive half-sine 3-kc wave, are delivered to the line through a hybrid coil at a peak voltage of about 20 volts. An adjustable balancing network is provided which can be set to balance the particular type of line being measured. A balance setting sufficient to introduce an additional loss of 25 to 30 decibels in the pulse energy that passes directly across the hybrid coil into the receiving amplifier will permit, without overloading, sufficient receiving sensitivity for ordinary fault finding. The pulses returning as reflections from faults in the line enter the receiving amplifier and appear as vertical deflections on the screen of the cathode ray tube.

A second oscillator output feeds through the measuring circuit into the sweep circuit where it controls the frequency of the horizontal sweep. The zero adjusting circuit and the measuring circuit provide individual continuous control of the phases of the voltages supplied to the pulse sending and sweep circuits respectively, thus permitting the times at which electrical events in these circuits take place to be adjusted with respect to each other. A simple procedure measures the round-trip time of the repeated pulses in terms of difference in phase between sending and measuring circuits. The result can be read from a single dial with arbitrary scale divisions. The fault distance is then obtained from a substantially linear plot between dial divisions and distances obtained experimentally or by simple proportion when compared to the dial reading for an artificial fault introduced at a known distance along a

particular line. The use of two phase adjustments permits measuring between any points along a circuit since the zero point can be set at any point desired along the circuit.

The original requirement to which the Lookator was built specified operation particularly on loaded spiral-four cable (CC358), having a nominal velocity of 18,000 miles per second. This 4-conductor cable is made in one-quarter mile lengths with bayonet connectors at the ends. Locations were required to be made over a length up to 35 miles with a desired accuracy of plus or minus one quarter-mile loading section. In addition, it was desired to operate the fault finding gear through carrier repeaters and other line equipment having a lower cut-off in the order of 200 cycles. A 200-cycle repetition rate would permit measurement of a total length of 45 miles without overlapping of pulses. A repetition rate of 220 cycles was selected so as to place the oscillator frequency equally distant from the harmonics of 60- or 50-cycle power supply. If noise is present on a faulty circuit, this prevents the possibility of power harmonics synchronizing

Figure 10. Front view of Lookator with cover removed



with the sweep which would cause troublesome standing patterns and possibly interfere with measurements. The 220-cycle rate permits measurements on circuits up to approximately 40 miles long.

After some experience with an experimental model, a further requirement was added, namely, operation on copper open-wire lines. The velocity of transmission for these circuits is in the order of ten times that of spiral-four cable. A different set of circuit elements for oscillator, phasing, and sweep circuits would ordinarily be indicated for open wire measurements in order to reduce cramping of the scale. In the instrument described here, however, only a single combination was provided, resulting in considerable simplification in equipment and operation, and retaining sufficient accuracy to meet requirements.

The relatively flat attenuation and velocity characteristics of spiral-four cable and copper open-wire over a range of 200 cycles to, say, 16 kc, allows operation over the required circuit lengths with a permissible amount of distortion of the pulse. If this same proportioned pulse were applied to a circuit of widely differing high frequency attenuation characteristics, the top of the returning pulse might become too rounded to use for measuring. Again, if it were contemplated to use this technique on circuits of very short electrical length, the measurement of much shorter time intervals would require a change in design of some of the apparatus components.

The measuring procedure is as follows: After turning the instrument on, with no line connected, a trace appears on the cathode-ray tube screen as shown in Figure 12A. The sharp projection above the horizontal is the measuring pulse that

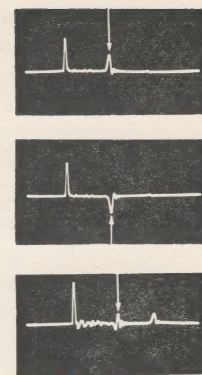
has passed across the hybrid coil because of the unbalance resulting from the open circuited line terminals. After placing the *MEASURE* dial on zero, the *INITIAL ZERO* dial is turned until the peak of the measuring pulse moves behind the vertical index line as shown in Figure 12B, thus setting the instrument on zero in preparation for a measurement. The circuit to be tested is then connected by operating the *TEST* key. Assuming a proper network setting, the original pulse at its normal position is now greatly reduced by the increased loss across the hybrid coil. If a fault is present, it will appear in some characteristic fashion on the trace, and in a position along the trace that represents the distance to it. The height of the pattern can be adjusted for examination. Figure 12C illustrates an open (both wires) in a spiral-four cable pair 11 miles from the Lookator. To measure the distance to this fault, the *MEASURE* dial is turned to move the pattern toward the index line until the peak of the pattern aligns with the index line as shown in Figure 12D. The reading of the *MEASURE* dial is an indication of the distance to the fault.

From the standpoint of a measurement of time, one turn of the *MEASURE* dial represents 1/220 second, or 22.7 microseconds for each division of the 220 division dial. Each division of the dial represents approximately 0.2 mile of spiral-four cable or 2.0 miles of copper open wire. Although the base width of the half-sine measuring pulse extends over several dial divisions, proper placement of the pulse tip permits a duplication of readings within 0.2-0.3 dial division, or a time of approximately 5 microseconds.

Examples of several types of faults on spiral-four cable are shown on Figure 13 which illustrates the possibilities of identi-

Figure 13. Examples of faults on spiral-four cables

A—Open circuit (2 two wires)
B—Short circuit
C—Missing loading coil



fying the nature of the faults. For the patterns shown, the balancing network has been adjusted off-balance intentionally to show the original pulse at the left of a sufficient height to indicate its position with reference to the trouble pattern. With the network properly adjusted, the original pulse becomes very small when the test line is connected. An open is indicated in Figure 13A, a short Figure 13B, and a missing loading coil in Figure 13C. The latter trace shows an open at the end of the 20-mile circuit in addition to the missing loading coil 10 miles out. This illustrates the ability of the Lookator to "look" through faults that are not gross faults and show others farther along on the circuit. The faults can be readily located whether they are steady or intermittent. Noise would tend to broaden the trace but even considerable amounts would not seriously interfere with the location of the irregularities.

A supplementary terminating unit, although not required for the operation of the Lookator, is of assistance in definitely identifying a particular defective 1/4-mile section of spiral-four cable. This device can be connected into the cable at any of the bayonet connector points by inserting the unit between the two connectors. Test keys permit the circuit being tested to be connected back upon the opposite pair or toward either pair beyond, thus providing an option of several terminations. If a fault is indicated at the Lookator with the pair in question connected normally through and disappears when terminated otherwise, then the fault is beyond this particular connection point. If, after connecting the terminating unit at a point farther along the circuit, the fault remains showing regardless of the termination employed, then the fault is between the Lookator and the terminating unit.

Figure 14 shows a special application for locating troubles in spiral-four cable beyond the first repeater section by measuring through one or more spiral-four carrier repeaters. The hybrid coil and

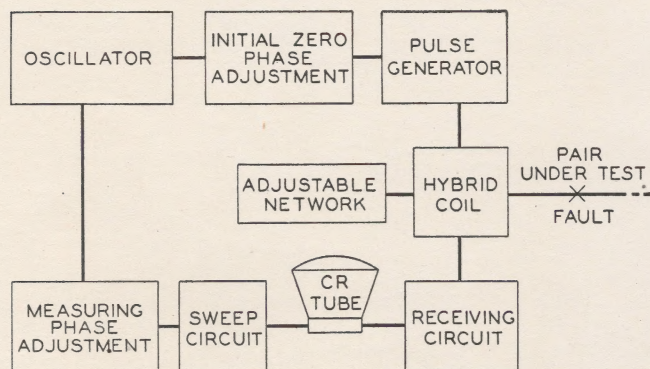
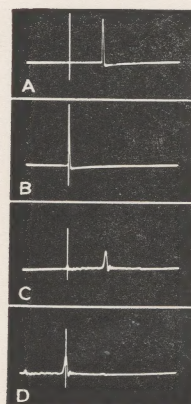


Figure 12 (left). Example of Lookator measuring procedure

A—Measuring pulse
B—Adjust initial zero
C—Connect line and note fault
D—Measure distance to fault by turning measure dial until fault pulse aligns with index line

Figure 11 (right). Block schematic diagram of Lookator for testing 2-wire circuit



network circuit in the Lookator are switched out, and a small hybrid unit containing the equivalent equipment is connected in at the intermediate repeater point preceding the section in trouble. The Lookator in this case is connected on a 4-wire basis with the sending and receiving sides of the carrier system used as long 4-wire leads to the hybrid coil circuit. The Lookator zero is set with the faulty circuit disconnected from the hybrid unit. The circuit beyond is then connected, and the result given by the Lookator is in terms of distance beyond the repeater point where the hybrid unit is being used. It is not expected that the nature of the faults will be as clearly defined in this type of measurement as when testing directly into a line. This is because of distortions which result when operating through the intermediate repeaters with normal line settings.

If the Lookator could always connect directly to a line of the same makeup throughout its length, conditions would be relatively simple. Unfortunately this is not always realized. On open wire, for instance, short runs of entrance cable, submarine cable, or insulated field wire may be encountered. Since there is an impedance change at points where the circuit changes, these irregularities will appear in the Lookator trace of the overall circuit. In addition, since the velocity through different types of facility will not be the same, the slope of the calibration curve will change when the facility

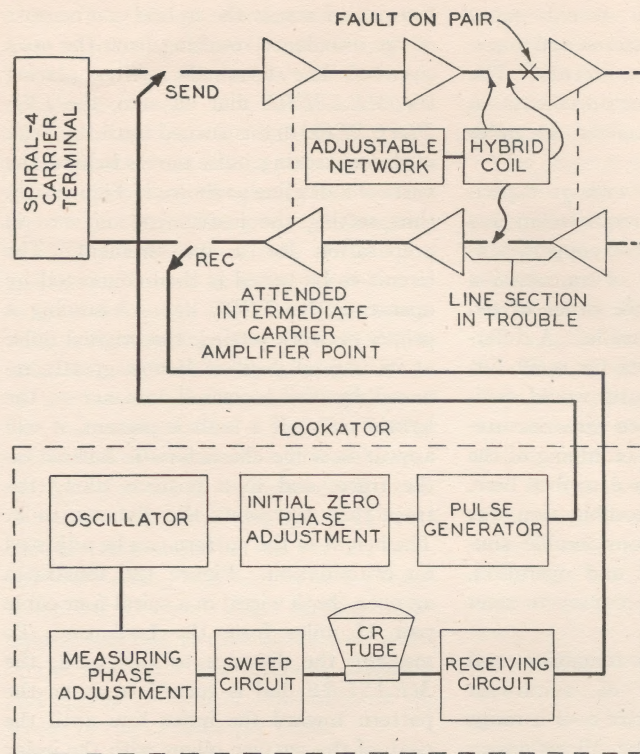


Figure 14. Block schematic of Lookator for testing through a repeater

changes. For such cases, a sort of road map interpretation of the Lookator trace will be necessary. If calibration or reference measurements are made at any convenient time to locate the strategic points on the circuit where the makeup

changes, these readings will serve as a guide to sectionalize trouble along the line. If then a reading is obtained between two reference points where the circuit makeup remains the same, distance within the section may be obtained by simple proportion, since the dial is approximately linear with distance between section reference points.

Conclusion

The use of repeated pulses to locate irregularities and to determine their magnitudes has proved worth while.

Further development to widen the fields of usefulness of such devices and to use them for somewhat different purposes is in progress.

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